Nanotechnology: Where Does the U.S. Stand?

Testimony before the Research Subcommittee of the House Committee on Science
Matthew M. Nordan, Vice President of Research, Lux Research Inc., June 29, 2005

The U.S. leads the world in nanotechnology today, but its position is tenuous. To maintain global leadership, U.S. policy makers must grow federal funding for nanotech research; eliminate regulatory uncertainty surrounding environmental, health, and safety issues; and do a better job of retaining foreign Ph.D. students. In addition, the U.S. must create financial incentives aligned with desirable applications and approach export controls sensibly.

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The U.S. Leads the World in Nanotechnology Today

Nanotechnology is the purposeful engineering of matter at scales of less than 100 nanometers (nm) to achieve size-dependent properties and functions. Nanotech innovations occupy a value chain starting with nanomaterials like carbon nanotubes and dendrimers, followed by intermediate products like memory chips and drug delivery carriers built with nanomaterials, and ending with enhanced final goods like mobile phones and cancer therapies (see Figure 1). Lux Research projects that new, emerging nanotechnology applications will affect nearly every type of manufactured good over the next ten years, becoming incorporated into 15% of global manufacturing output totaling $2.6 trillion in 2014 (see Figures 2 and 3).[1]

Multiple Metrics Testify to the Position of the U.S.

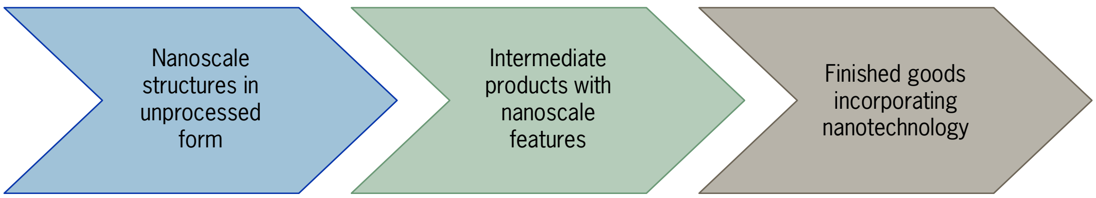
Massive investment is going into nanotech – $8.6 billion combined in government spending, corporate R&D, and venture capital worldwide in 2004, up 10% from 2003 (see Figure 4-1).[2] By most measures, the U.S. leads in nanotechnology today, including:

- **Absolute public sector spending.** Of the $4.6 billion spent by governments on nanotechnology R&D last year, the U.S. led in absolute terms with nearly $1.6 billion; runner-up Japan spent less than two-thirds as much at $1.0 billion (see Figure 4-2).[3]
- **Patents issued.** U.S. leadership in patent activity in general is amplified when it comes to nanotechnology. While 56% of total issued patents at the U.S. Patent and Trademark Office are assigned to U.S.-based entities, 69% of nanotech patents are.[4]

Fig. 1: Nanotech Adds Value across Industry Value Chains in Three Stages

The nanotechnology value chain

Nanomaterials	Nanointermediates	Nano-enabled products



Nanomaterials	Nanointermediates	Nano-enabled products
Nanoparticles, nanotubes, quantum dots, fullerenes, dendrimers, nanoporous materials, etc.	Coatings, fabrics, memory and logic chips, contrast media, optical components, orthopedic materials, superconducting wire, etc.	Cars, clothing, airplanes, computers, consumer electronics devices, pharmaceuticals, processed food, plastic containers, appliances, etc.

Source: October 2004 Lux Research report "Sizing Nanotechnology's Value Chain"

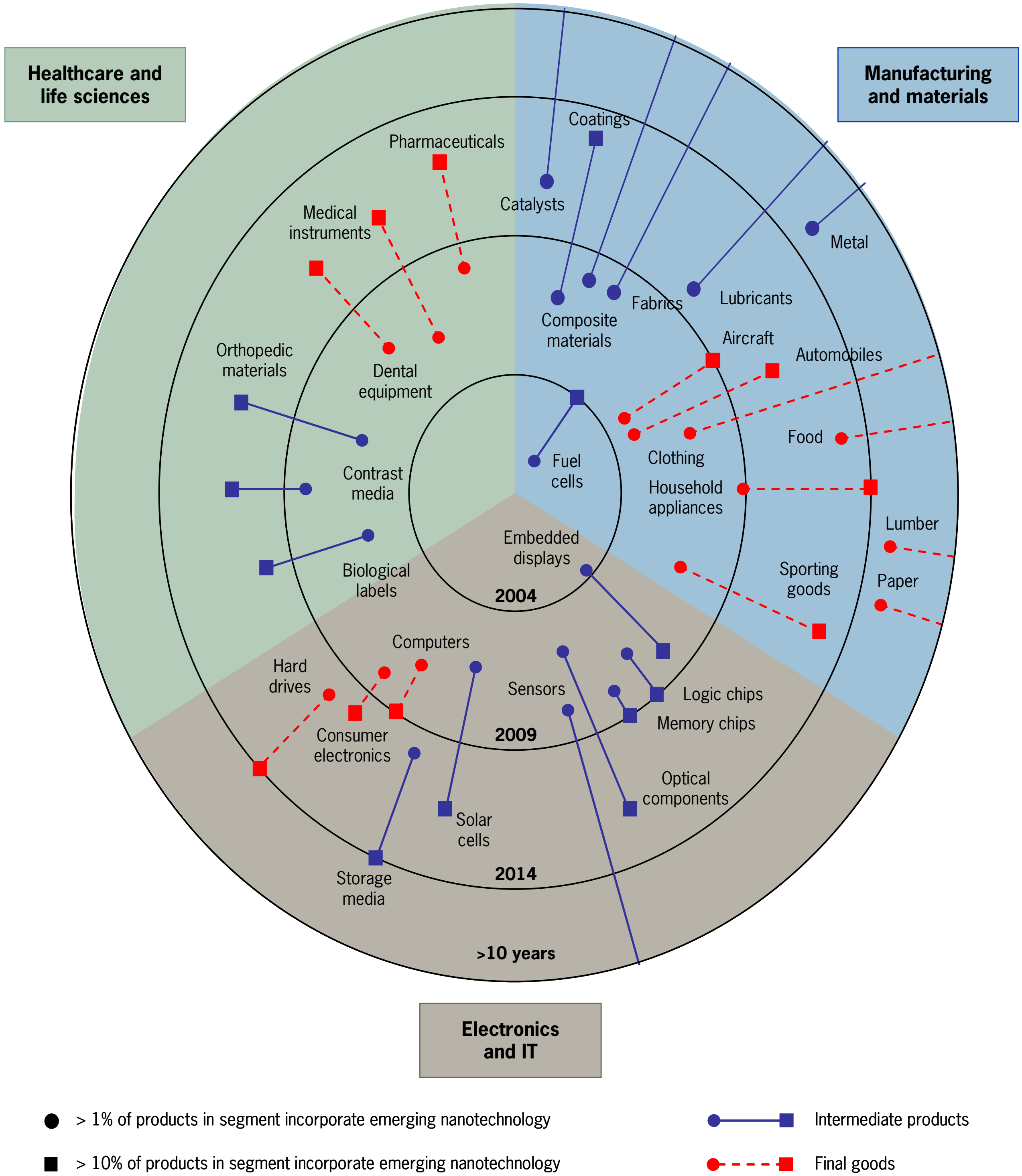
- **Corporate R&D spending.** We conservatively estimate that corporations worldwide spent $3.8 billion on nanotechnology R&D in 2004; of this, $1.7 billion was spent by corporations based in the U.S., far more than in any other country (see Figure 4-3).[5]
- **Scientific publications.** Of a representative sample of 109,728 articles published in peer-reviewed journals about nanoscience and nanotechnology through June 2005, 24% were authored by U.S.-based scientists – exceeding second-place China (at 13%) and third-place Japan (at 11%) by a wide margin (see Figure 4-4).[6]

Deeply Embedded Sociocultural Values Drive U.S. Leadership

The U.S. owes its leadership position in nanotechnology to wise decisions, made by both governments and private sector entities like venture capital investors, about how science and technology innovations should be commercialized. These decisions, in turn, stem from deeply embedded sociocultural values – for example, that successful risk-taking innovators should capture large rewards, and that short-term failure is a step toward long-term success. The U.S. benefits from:

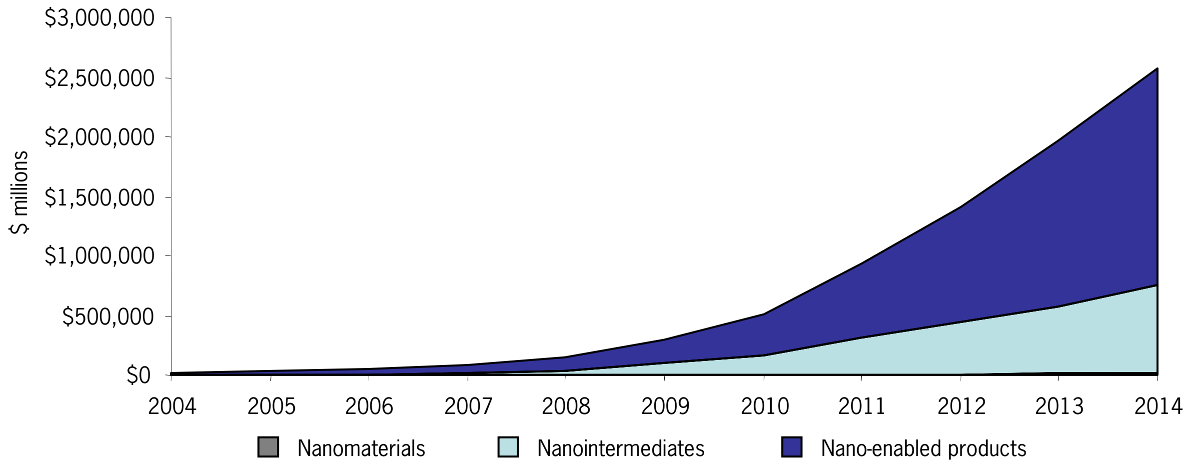
- **World-class universities that create grist for the commercialization mill.** Universities provide an effective vehicle for transferring cutting-edge technology from the lab to the manufacturing floor.[7] The U.S. serves as a model for the world in this regard, for both high technology in general and nanotech in particular. U.S. investment in knowledge as a percentage of GDP totaled 6.8% in 2000, topping the league tables of the first-world OECD countries.[8] The Bayh-Dole Act of 1980 gave universities powerful financial incentives to transfer innovation into commercial entities, and corporations working in nanotech eagerly tap these resources: 85% of corporations active in nanotech R&D interviewed by Lux Research in Q4 2004 have university collaborations.[9]
- **A culture of entrepreneurship that thrives on constructive failure.** In the U.S., leaving a comfortable corporate job to launch a start-up company is widely considered a positive

Fig. 2: Product Categories Will Incorporate Emerging Nanotechnology at Different Rates



Source: October 2004 Lux Research report "Sizing Nanotechnology's Value Chain"

Fig. 3: Global Sales of Products Incorporating Emerging Nanotechnology, by Value Chain Stage, 2004 to 2014



Source: October 2004 Lux Research report "Sizing Nanotechnology's Value Chain"

career move. In other first-world countries, it may either be viewed as foolish or be nearly impossible to accomplish. Hotbeds like Massachusetts's Route 128, California's Silicon Valley, and Texas's greater Austin area teem with the combination of innovative thinkers, technical talent, and experienced management needed to forge a successful start-up. It's no surprise that, of approximately 1,200 nanotech start-ups active in 2004, half were located in the U.S.[10]

- **World-leading availability of risk capital.** Although corporations do an effective job of incubating incremental nanotechnology applications that complement their existing products, disruptive nanotechnology applications overwhelmingly arise from start-up companies such as Aspen Aerogels, Nanospectra Biosciences, and Nantero. Venture capital is the lifeblood of these small firms, and the U.S. claims 56% of venture capital deployed in start-ups globally.[11]

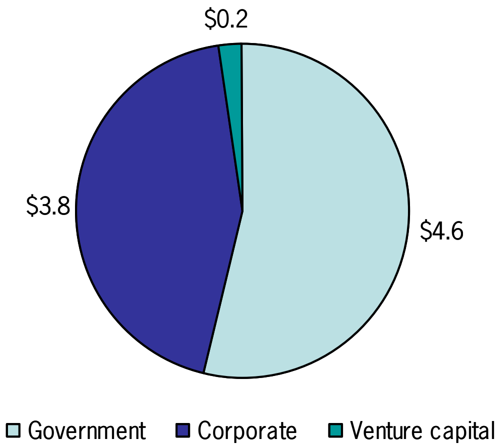
The Dominant U.S. Position in Nanotechnology Lies at Risk

Despite the U.S.'s strong position in nanotechnology, other countries – from the usual suspects like Japan and South Korea to surprises like Australia and Israel – challenge its dominance. Witness:

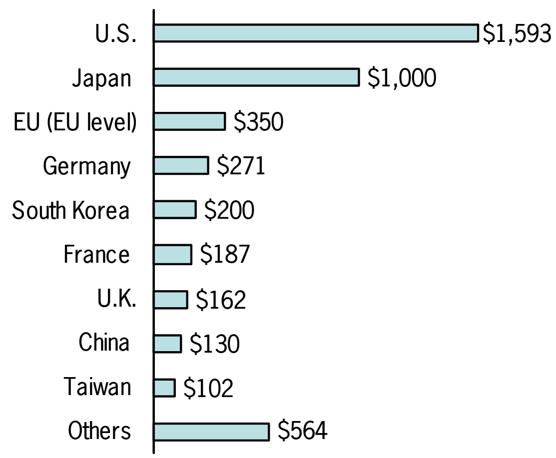
- **U.S. loss of spending leadership on a relative basis.** Although the U.S. puts more government funding to work on nanotech research than any other country on an *absolute* basis, it has already fallen behind Asian competitors on a *relative* basis. This trend becomes even more apparent when spending levels are corrected for purchasing-power parity, reflecting the difference in what a dollar buys from one country to the next. On this basis, the U.S. invested $5.42 per capita in government spending on nanotechnology last year, exceeded by South Korea at $5.62, Japan at $6.30, and Taiwan at $9.40 – nearly twice the level of the U.S. (see Figure 5-1).[12]

Fig. 4: The U.S. Leads the World in Nanotechnology Today

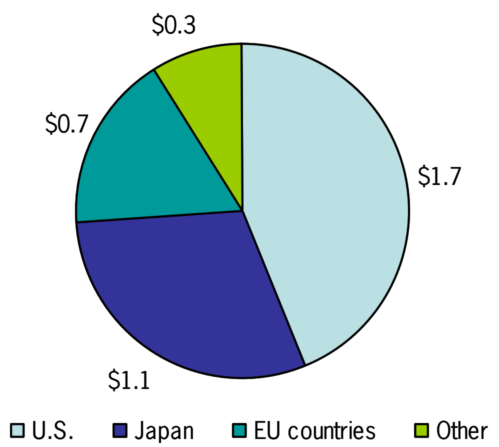
4-1: Global nanotech funding, 2004 ($ billions)



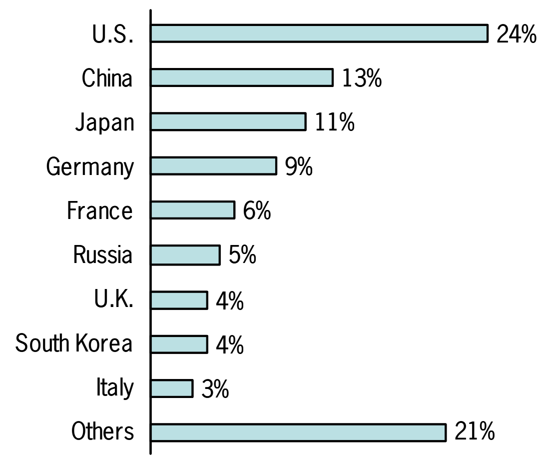
4-2: Government nanotech funding, 2004 ($ millions)



4-3: Corporate nanotech R&D, 2004 ($ billions)



4-4: Country of origin of nanotech scientific articles, through June 2005

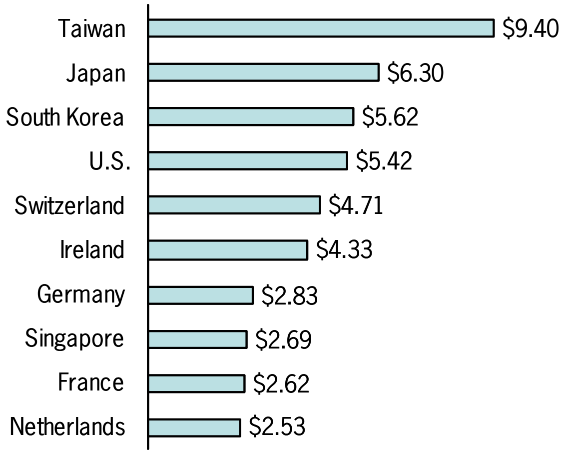


Source: 2004 Lux Research reference study "The Nanotech Report 2004;" Science Citation Index search (see endnote 6)

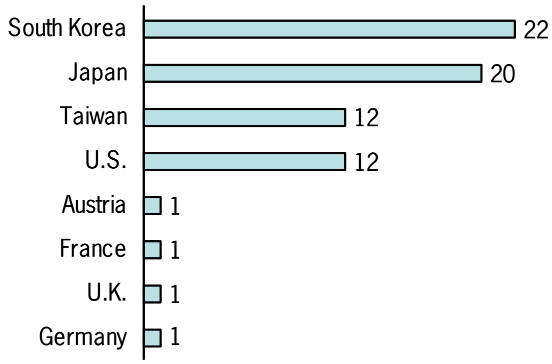
- **Industrial policy abroad aimed at dominating specific product segments.** U.S. industrial policy eschews direct government/industry collaboration for leadership in specific applications. In Europe and Asia, many governments pursue the strategies that the U.S. avoids, giving foreign competitors a leg up on their U.S. rivals. For example, of the $640 million allocated to Taiwan's Nanoscience and Nanotechnology Initiative over five years, 60% is earmarked for "strategic industry applications" developed collaboratively between government institutions and industrial champions.[13] Two of Taiwan's top nanotechnology applications are magnetoresistive RAM,

Fig. 5: The Dominant U.S. Position in Nanotechnology Lies at Risk

5-1: Government nanotech funding, 2004, per capita at purchasing-power parity



5-2: U.S. patents issued for carbon nanotube display applications, by country, through February 2005



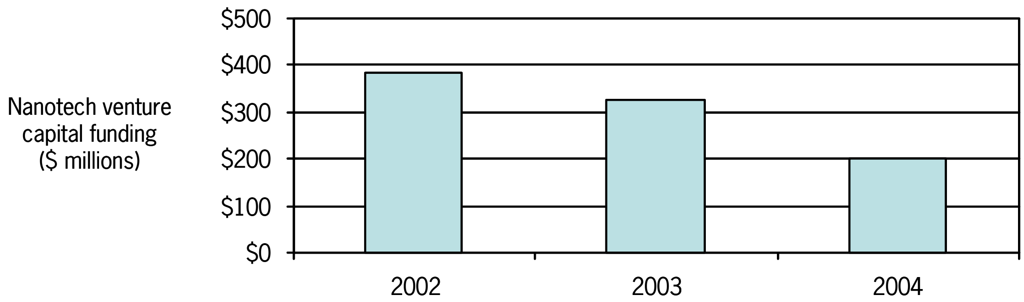
Source: Published spending allocations and Lux Research analysis; U.S. Patent and Trademark Office searches

which U.S. companies Freescale Semiconductor, IBM, and NVE have been developing for more than a decade, and carbon nanotube field emission displays, which U.S.-based electronics giant Motorola, small-cap company Nano-Proprietary, and start-up cDream are working on.[14]

- **Leadership of high-volume, near-term applications on foreign shores.** In many specific, promising application domains, researchers in other countries have begun to outpace the U.S. in developing intellectual property – even when measured by patents issued within the U.S. patent system. Consider carbon nanotubes in displays, where the wonder materials have been proposed for a new type of large, flat-panel monitor that could outperform LCD and plasma at lower cost and energy consumption. Of 70 patents for carbon nanotube display applications issued by the U.S. Patent and Trademark Office through February 2005, only 17% were issued to entities based in the U.S. compared with 29% in Japan and 31% in South Korea (see Figure 5-2).

- **Innovative efforts in unexpected places.** Scientists in countries with a less rich history of science and technology innovation are not lagging when it comes to nanotech. On the contrary, they are studying U.S. scientific publications, being educated in U.S. universities, and orienting their initial capital investments toward the instrumentation needed for nanotechnology research, without having to maintain technology infrastructures and skill sets that were cutting-edge 20 years ago. The result: impressive efforts in countries not known for scientific leadership. The $130 million in estimated government spending on nanotech last year in China equaled $611 million at purchasing-power parity, or 38% of U.S. expenditure; in addition, China recently launched a world-leading effort to set standards for nanomaterials.[15] Further, some countries that the U.S. considers to represent strategic threats have thriving nanotech programs; the Iranian NanoTechnology Initiative was ordered by none other than President Mohammed Khatami.[16]

Fig. 6: Venture Capital Funding Invested in Nanotech Start-Ups, 2002 to 2004



Source: 2004 Lux Research reference study "The Nanotech Report 2004"

- **Lack of concern with violating intellectual property (IP) protection.** Companies exploiting nanotechnology depend on international property protection to defend their freedom to operate. Yet in many foreign countries, lax enforcement of intellectual property means that rivals appear to ignore patents in practice. In the crowded field of metal oxide nanoparticles, with applications in everything from sunscreens to rocket fuels, 74 companies compete globally, eight of which are in China. The U.S.- and European-based companies – like NanoGram, Nanophase, and Nanotechnologies Inc., – depend on proprietary, patented production processes. for their differentiation and financial valuations. But the Chinese manufacturers stress their ability to deliver identical products at prices 15% to 20% cheaper – and generally refuse to name their production processes, raising suspicion that they are using Westerners' patent filings like recipe books. With lax Chinese IP enforcement and no way to infer a manufacturing process from the nanoparticles that result, U.S. nanoparticle firms have limited means to compete.

Entrepreneurs Face Steep Hurdles on the Path from University Lab to Successful Start-Up

For the U.S. to remain highly competitive, it must help start-ups overcome:

- **Funding gaps.** The widespread perception that nanotechnology start-ups have more venture capital than they can reasonably deploy is dead wrong. In fact, venture funding for nanotechnology start-ups declined from $385 million in 2002 to $200 million in 2004, and accounted for only 2% of nanotechnology R&D funding that year; cautious VCs burned by the Internet bubble hesitate to commit more cash until they see substantial exits (see Figure 6).[17] To encourage entrepreneurs to bring nanotech innovations out of university laboratories and into the commercial arena, government funding through vehicles like Small Business Innovation Research (SBIR) grants and the National Institute of Science and Technology's Advanced Technology Program (ATP) is an absolute necessity.

- **Human resource gaps.** The U.S. is not generating enough Science and Engineering Master's degree and Ph.D. holders to maintain leadership in nanotechnology. Tighter controls on student visas since the September 11 attacks have reduced the inflow of Ph.D. students to the United States in favor of Western Europe, and as economies in China, India, and South Korea develop, foreign scientists are less likely to remain in the U.S. for their careers than they were a decade ago. Nobel Laureate Richard Smalley from Rice University has noted that at current rates, by 2010, 90% of all physical scientists will be Asian and 50% of them will be practicing in Asia.

- **Manufacturability gaps.** Nanotechnology start-ups must cross a much ballyhooed "valley of death" to obtain the risk capital funding required to move the business forward. Yet they also must cross another, related, valley between small-scale benchtop production volumes and the pilot-scale production required to win commercial contracts. Our contacts with nanotechnology researchers indicate that the Nanoscale Science Research Centers scattered throughout the U.S. assist with basic research only (not scale-up), are ill-used, and do not help bridge this gap. As a result, many start-ups spend redundant millions to build the same manufacturing pilot plants that they end up using perhaps 10% of the time; dedicated, shared manufacturing facilities devoted to technology incubation would help bridge this gap more cost-effectively.

The U.S. Government Must Take Concerted Action to Maintain Leadership

We recommend that the U.S. government:

- **Grow federal funding for nanotechnology research.** To maintain leadership, the U.S. National Nanotechnology Initiative (NNI) must be funded at or beyond current budget request levels. It should not be assumed that U.S. states will pick up any slack should federal spending ebb: Although U.S. states spent $432 million last year, complementing approximately $1.15 billion at the federal level, most of this money went to initial purchases of equipment and construction of facilities, not to funding ongoing research activity by Ph.D. and postdoctoral students. This state spending essentially represents one-time capital expenditure unlikely to be sustained.

- **Eliminate uncertainty surrounding environmental, health, and safety (EHS) issues.** Nanoparticles present new EHS issues; not enough fundamental toxicity research has been done on nanoparticles to decisively determine what hazards they may pose to workers, the public, and the environment – or how such hazards may be mitigated. We believe fundamental research on nanoparticle toxicity can realistically be performed only under a government aegis; to perform it, the U.S. government must at least double the small sums currently allocated at the federal level for nanotech EHS research, which totaled only 3.7% of the 2006 NNI request (see Figure 7).[18]

  Beyond fundamental research, agencies like the Environmental Protection Agency have not yet established firm guidelines for how new nanoparticles will be treated under existing, or potentially new, regulatory schemes. While this unwillingness to rush to judgment before all the facts are in is well intentioned, it has perverse effects: Based on our contact with individuals driving nanotech initiatives at America's largest corporations, it's clear to us that ambiguity surrounding EHS regulation of nanoparticles is hampering commercialization – firms do not want to play a game whose rules may change at any time. To move forward, the EPA, the FDA, and NIOSH must issue clear guidance to industry on how they plan to approach nanoparticles.

- **Attract U.S. students to science and engineering and retain foreign ones.** As with many science and technology fields, funding and development incentives for nanotechnology research will amount to nothing without a steady stream of advanced science and engineering degree holders entering the workforce. The U.S. should strengthen programs designed to inspire

Fig. 7: U.S. Government Spending on Nanotech EHS Research Is Insufficient

Organization/initiative/program	Total nanotech spending ($ millions)	Nanotech EHS spending ($ millions)	Total budget ($ millions)
National Nanotechnology Initiative (FY2006 projection)	$1,100	$38.4	$1,100
National Science Foundation (funding awarded to date)	$345	$8.3	$5,500
Environmental Protection Agency (program announced November 12, 2004)	$4	$4	$7,600
National Toxicology Program (currently earmarked for nanomaterial toxicology studies)	$0.5	$0.5	$183

Source: May 2005 Lux Research report "A Prudent Approach to Nanotech Environmental, Health, and Safety Risks"

students with wonder for the physical sciences in K–12 education, reconsider the effect of visa tightening on the inflow of foreign science and technology graduate students, and develop economic incentives for foreign science and technology graduates to remain in the United States rather than repatriate, taking with them the skills they acquired in the U.S.

- **Create financial incentives aligned with desirable applications.** We believe U.S. economic development policy is right not to fund specific solutions to broad technology problems. However, the U.S. would be well served by government programs that provide funds to nanotechnology researchers, giving them incentives to develop applications with well-defined *ends,* without specifying particular technology *means*. Such programs can be coordinated through existing agencies and require no incremental bureaucracy.

  Consider NASA's $11 million project with Rice University to develop extremely low-loss power cables based on carbon nanotubes: Such cables could enable a national power grid, shuttling electricity from locations of sustainable resources to areas of high demand without losing it on the way. The National Renewable Energy Laboratory estimates that solar cells covering a 100- by 100-mile area in Nevada could meet the U.S.'s entire energy needs, but without low-loss power cables the electricity could never reach demand hubs like Chicago and New York.[19]

- **Employ export controls sensibly, without choking nanotech commercialization.** Export controls for products incorporating nanotechnology have become a hot topic inside the Beltway; individuals representing multiple organizations across branches of government have independently sought Lux Research's advice on this issue. We believe that export controls for "nanotechnology" per se are a dead end. The field is too broad; such action would be like trying to impose export controls on assembly-line manufacturing techniques and the equipment used to implement them – impossible to carry out rationally. Instead, we believe the U.S. should identify relevant nanotechnology *applications* (e.g., radiation-hardened solar cells, high-frequency beam-steerable antennas, nanoparticulate propellants and explosives) and impose sensible export controls on them within existing frameworks rather than introducing new ones.

Endnotes

1 Source: October 2004 Lux Research report "Sizing Nanotechnology's Value Chain."

2 Source: 2004 Lux Research reference study "The Nanotech Report 2004."

3 Source: 2004 Lux Research reference study "The Nanotech Report 2004."

4 Source: USPTO searches as of June 22, 2005. For more information on nanotechnology and patents, see the March 2005 Lux Research report "The Nanotech Intellectual Property Landscape."

5 Source: 2004 Lux Research reference study "The Nanotech Report 2004."

6 To identify these articles, we used the Science Citation Index with a search string of "(quantum dot OR nanopartic* OR nanotub* OR fullerene* OR nanomaterials* OR nanofib* OR nanotech* OR nanocryst* OR nanocomposit* OR nanohorn*)."

7 It should be noted that national labs such as Oak Ridge and Sandia also serve as wellsprings for innovation that can be commercialized down the road.

8 Source: OECD Factbook 2005.

9 Source: December 2004 Lux Research report "The CEO's Nanotechnology Playbook."

10 Source: 2004 Lux Research reference study "The Nanotech Report 2004."

11 Source: Lux Research analysis based on Thomson Venture Economics and IMD World Competitiveness Yearbook 2004.

12 Source: Published spending allocations and Lux Research analysis.

13 Source: "The Strategy and Experiences to Industrializing Nanotechnology in Taiwan," presentation delivered at SEMI NanoForum 2004, November 15, 2004, by Tsung-Tsan Su, Ph.D., General Director, Nanotechnology Research Center, Industrial Technology Research Institute, Taiwan.

14 Such initiatives do not exist only in Asia. In Europe, the NanoCMOS project aims to reach the 45-nm semiconductor process node in 2005, well ahead of the International Technology Roadmap for Semiconductors targets. It received €24 million in initial funding from the European Commission and is being executed by a consortium anchored by semiconductor heavyweights Infineon (Germany), Philips (the Netherlands), and STMicroelectronics (France).

15 Source: Lux Research analysis.

16 Source: "Revolutionary Nanotechnology," *Hamshahri* (Iranian daily newspaper), No. 3651, page 10, March 3, 2005. Accessed via http://www.netiran.com/?fn=artd(3434).

17 Source: 2004 Lux Research reference study "The Nanotech Report 2004."

18 Source: May 2005 Lux Research report "A Prudent Approach to Nanotech Environmental, Health, and Safety Risks."

19 Source: John A. Turner, "A Realizable Renewable Energy Future," *Science*, Vol. 285, Issue 5428, pp. 687-689, July 30, 1999.